

Servicing Capability for the Evolutionary Space Station

GSFC Work Package 3

**Servicing
Contract NAS5-30363**

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Introduction

User servicing for Space Station Freedom(SSF) will span an evolutionary period paralleling that of the station's growth plan. This will include a baseline servicing configuration followed by a final growth phase in which all user servicing requirements are satisfied. Although the basic requirements for user servicing are not station configuration dependent, the emphasis placed on different aspects of servicing may change with the eventual SSF growth objectives.

This paper will discuss the servicing requirements and how they will be satisfied by Freedom baseline and growth capabilities. The accommodation of the growth servicing elements will be addressed, including the required hooks and scars to implement these growth servicing capabilities.

Overview

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User Servicing Definitions

The terms used to describe user servicing have been defined to ensure consistency in their meaning and to limit their scope. The definitions given represent basic servicing activities which may be combined to describe a complete servicing operation. For example, servicing an Orbital Replaceable Unit (ORU) consists of several activities, such as transfer, disassembly, replacement, assembly, and check-out. A detailed description of user servicing definitions and implementation is presented in the Servicing System Implementation Definition Document, SSP 30501. The activities covered by user servicing include those performed in the external, unpressurized areas of the Space Station Freedom (SSF) and are limited to user hardware.

User Servicing Definitions

Assembly -	Payload integration, checkout, assembly, and disassembly
Restore -	Inspection, replacement/repair, test, and calibration
Storage -	Unpressurized with thermal and contamination protection
Transportation -	Retrieve, deploy, and boost to operational orbit
Transfer -	Payload, ORU, and free-flyer relocation on the external structure of the SSF
Replenishment -	User expended fluids, waste removal, harvesting products and raw product resupply

User Servicing Requirements

With the increased capabilities provided by a permanently manned space station and the presence of complex user hardware, it is necessary to plan for the servicing of this hardware. A complete assessment of servicing requirements for planned attached payloads, free-flyers, and co-orbiting platforms has been performed to ensure all user servicing needs will be satisfied by the user servicing system. The availability of user servicing capabilities are planned to parallel the increasing complexity of user hardware. This will ensure adequate growth servicing capabilities will be in place when required by users.

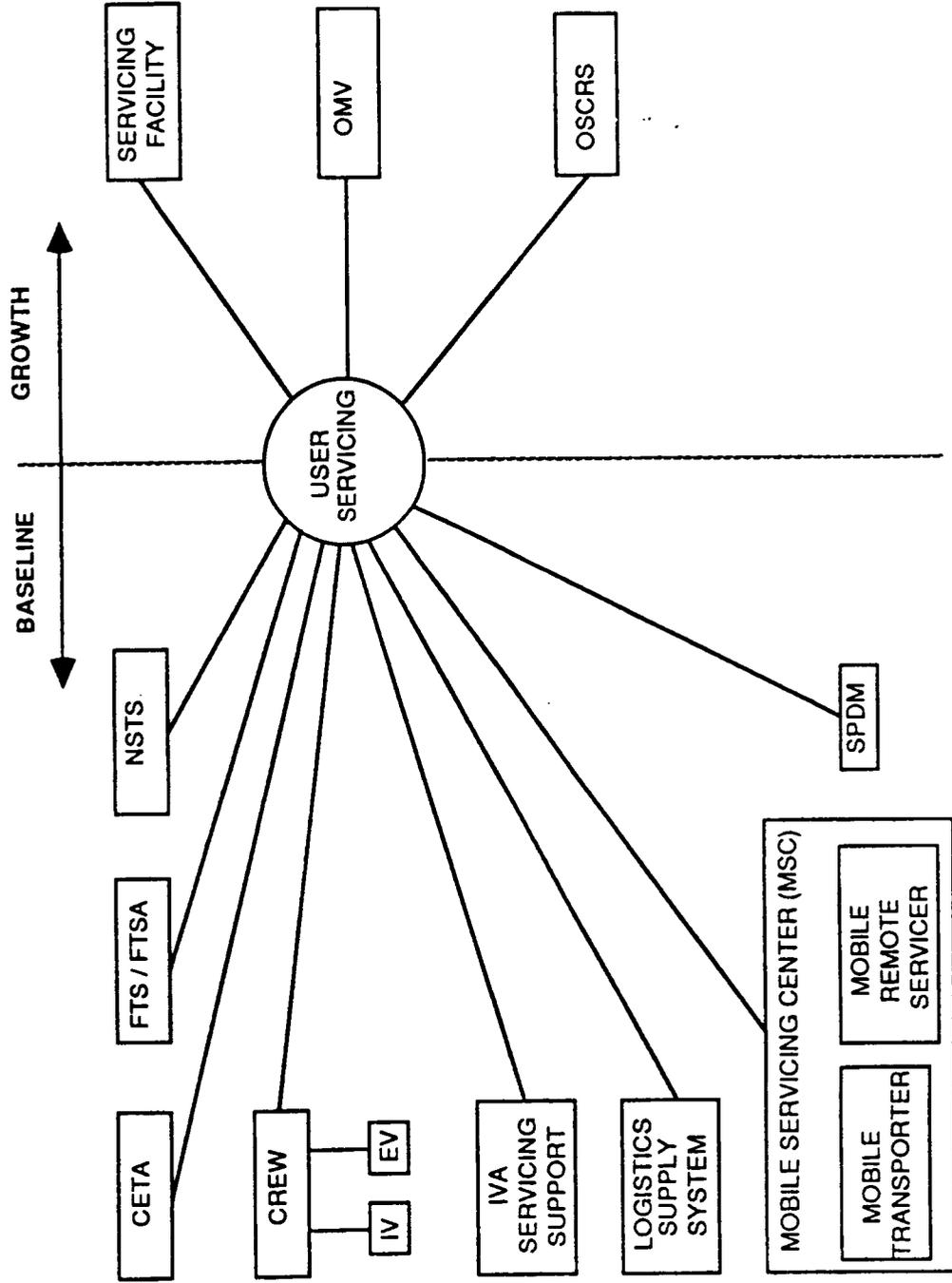
User Servicing Requirements

- User servicing requirements are derived from the necessity to service user hardware planned for the baseline and growth phases of SSF
- Assessment of user hardware included:
 - Attached Payloads
 - Free Flyers, including the Man Tended Free-Flyer (MTFF/ESA)
 - Co-orbiting Platforms
 - Free-Flyers and Co-orbiting Platforms in-situ servicing
- Assessment of user schedules to ensure availability of servicing capabilities
 - Limited servicing available to early attached payloads
 - Growth of capabilities to support complex servicing of attached payloads, Free-Flyers, and Co-orbiting Platforms

Servicing Architecture Configuration

The Servicing Architecture depicts the Freedom elements utilized for user servicing. The baseline user servicing system is made up of existing station and NSTS program elements. In addition, the figure illustrates those elements in the baseline and those elements which will be added in the growth phase. SSF elements will be used in conjunction with each other to accomplish a servicing activity.

Servicing Architecture Configuration



User Servicing Capabilities

User servicing capabilities are divided into two phases that parallel the evolution of Freedom. In the baseline configuration servicing elements will be shared by many systems on the station. These elements will provide basic servicing capabilities which include the transport and transfer of user hardware, the manipulation of equipment, access to SSF power and data resources, and the ability to monitor and inspect user hardware. During the station growth phase servicing unique elements will be added to complement the baseline elements. The growth elements will provide controlled storage, thermal control, and fluid replenishment, thus completing the servicing system.

User Servicing Capabilities

- Baseline Servicing Capabilities provides the following
 - Transfer
 - Manipulate Equipment
 - Access to SSF power and data resources
 - Monitor/Inspect
 - Temporary handling site
- Growth Servicing Capabilities add the following
 - Controlled storage
 - Thermal control
 - Fluid replenishment

Baseline Servicing Capabilities

A matrix was developed to assess Freedom's ability to satisfy required user servicing capabilities. The capabilities listed were derived from user servicing requirements. A check mark was used to indicate where a support element provided a required capability. Since no baseline support elements provide the capability for controlled storage, thermal control, contamination control, and fluid replenishment, SSF provides only limited user servicing. Furthermore, the lack of a transport capability does not provide the ability to service free-flyers and co-orbiting platforms. Therefore, baseline capabilities will only support limited servicing of attached payloads.

Baseline Servicing Capabilities

- Baseline user servicing capabilities will support limited servicing of attached payloads at their operational site or at a temporary locally adjacent site

Required User Servicing Capabilities	BASELINE SERVICING ELEMENTS										
	FTS	CETA	CREW			LSS*		MSC	SPDM		
			IVA	EVA	ULC	ULC	MSC			SPDM	
Transfer		✓		✓					✓		
Transport											
Manipulate Equipment	✓			✓					✓		✓
Controlled Storage											
Power & Data Resources									✓		
Thermal Control											
Contamination Control											
Fluid Replenishment											
Monitor/Inspect	✓			✓					✓		✓
Temporary Handling Site		✓							✓		✓

* Internal pressurized storage not included in this document

Note: Transport to the SSF not shown in this table, capability provided by NSTS

Growth Servicing Elements

Growth of the user servicing system will add SSF elements to support user servicing. These elements are the Customer Servicing Facility (CSF), the Orbital Spacecraft Consumables Resupply System (OSCRS), and the Orbital Maneuvering Vehicle (OMV).

Growth Servicing Elements

- Customer Servicing Facility (CSF)
- Orbital Maneuvering Vehicle (OMV)
- Orbital Spacecraft Consumables Resupply System (OSCRS)

Growth Servicing Capabilities

The growth elements were added to the baseline capabilities matrix in order to evaluate the total SSF servicing capabilities. An examination of this matrix illustrates that all required servicing capabilities are provided by one or more of the support elements. Therefore all known user servicing requirements are satisfied by the planned growth user servicing capabilities.

Growth Servicing Capabilities

- All known user servicing requirements are satisfied by the planned growth user servicing capabilities

Required User Servicing Capabilities	BASELINE SERVICING ELEMENTS										GROWTH ADDITIONS		
	FTS	CETA	CREW			LSS*		MSC	SPDM	CSF	OMV	OSCRS	
			IVA	EVA	✓	ULC							
Transfer		✓			✓			✓					
Transport											✓		
Manipulate Equipment	✓				✓			✓		✓			
Controlled Storage										✓			
Power & Data Resources								✓		✓			
Thermal Control										✓			
Contamination Control										✓			
Fluid Replenishment										✓		✓	
Monitor/Inspect	✓			✓	✓			✓		✓			
Temporary Handling Site		✓					✓			✓		✓	

* Internal pressurized storage not included in this document

Note: Transport to the SSF not shown in this table, capability provided by NSTS

Full Servicing Capabilities

The transport capability provided by the addition of the growth element, the OMV, allows free-flyers and co-orbiting platforms to be brought to SSF for servicing. The additional growth elements, the CSF and OSCRS, provide the capabilities for controlled storage, thermal control, contamination control, and fluid replenishment. Therefore, growth capabilities will support complex servicing of attached payloads, free-flyers, and co-orbiting platforms.

Full Servicing Capabilities

- Accommodates complex Attached Payload servicing
 - Thermal protection and contamination monitoring/control within an enclosed area
 - Complete functional checkout to verify successful completion of servicing activity
 - Fluid removal/resupply capability for user fluids (Cryogenics, Gases, etc.)
 - Controlled storage for replacement hardware, tools, and support equipment
 - Dedicated hardware to support complex EVA and robotic servicing tasks

- Accommodates complex Free-Flyer and Co-orbiting Platform servicing
 - Transport between operational orbit and SSF
 - Berthing and holding fixtures to support servicing activity
 - Temporary storage and complete functional checkout
 - Thermal protection, and contamination monitoring and control
 - Power, thermal, data management, and communication interfaces
 - Long term storage of replacement hardware, service tools, and support equipment
 - Fluid removal/resupply (Hydrazine, cryogenics, gases, etc.)
 - Dedicated hardware to support complex EVA and robotic servicing tasks

Accommodation of Growth Elements

The CSF provides the accommodation for the servicing, handling, and storage of the OMV and for the handling and storage of the OSCRS. The interface to freedom for the OMV and OSCRS is through the CSF. The CSF design results in a single interface between the SSF and all the growth servicing elements.

Accommodation of Growth Elements

- All growth servicing elements are accommodated within the Customer Servicing Facility (CSF)
- CSF provides storage, servicing, checkout and access for utilization of the Orbital Maneuvering Vehicle and the Orbital Spacecraft Consumables Resupply System

SSF Hook and Scar Requirements

The table shows the SSF distributed systems that require hooks and scars in order to accommodate the CSF. In addition to the distributed system scars, it is also necessary to reserve a location on the transverse boom to provide maximum operational flexibility in the use of the CSF.

SSF Evolutionary Growth Options

The final evolutionary path of the Space Station Freedom is yet to be determined. Both the Transportation Node and the Research and Development Station have been studied within the LaRC Evolutionary Working Group activity. Analysis of both designs has led to the conclusion that user servicing is an essential aspect of both evolutionary paths. The Research and Development evolutionary path will result in substantial user participation. This increased user participation will emphasize the requirements for user servicing. The Transportation Node evolutionary path will result in less user participation. However, the availability of Space Transfer Vehicles (STV) will allow greater access to free-flyer and co-orbiting platforms for servicing.

SSF Evolutionary Growth Options

- Proposed evolutionary paths for SSF will not effect the types of servicing events required by station users
- Evolution is likely to influence the quantity and make-up of user servicing events
- As a result the station evolutionary path will determine the demand on servicing capabilities

Servicing Evolutionary Studies

In addition to the work done to define the servicing system architecture (GE/TRW) some studies were performed to assess the evolutionary options of the servicing system and any impacts due to SSF evolution. These studies ranged from a CSF Relocation Assessment to an assessment of impacts on the user servicing system due to FTS evolution.

Servicing Evolutionary Studies

- Servicing Facility Proposed Relocation Assessment
- Hook and Scar Requirements for Growth User Servicing
- OMV, A User Servicing Support Element
- Space Station Freedom User Servicing Capabilities
- Space Transfer Vehicle Accommodations Impact to User Servicing
- Alternate User Servicing Growth Options; Station Keeping
- Space Station Freedom Transportation Node Analysis: Impacts to User Servicing
- Free Flyer Launch and Servicing Schedules
- Servicing Capability for the Evolutionary Space Station
- FTS Capabilities in Support of Growth User Servicing
- FTS Hooks & Scars in Support of Growth User Servicing

Selected Evolutionary Study Results

Each of these studies yielded conclusions and recommendations relative to their subject matter. Some of the conclusions reached are: do not relocate the CSF to the upper transverse boom; accommodating an STV on SSF will increase contamination potential, decrease the availability of servicing system elements, and limit direct viewing of both CSF proximity operations; evolving to a Transportation Node Space Station may necessitate relocating the CSF and will tie up many of the servicing elements.

Selected Evolutionary Study Results

- Recommended against CSF relocation to the upper surface of the transverse boom
 - Interference with the radiator panels
 - Limited viewing of OMV/free-flyer proximity operations
- STV Accommodations adversely impact the User Servicing System
 - Increased contamination potential (due to refuelling operations)
 - Decreased availability of Servicing System elements (OMV, FTS, etc.)
 - Interferes with viewing of the CSF and CSF proximity operations
- Evolutionary growth to a Transportation Node affects the User Servicing System
 - STV provides greater range for accessing payloads for servicing
 - Module growth for a Transportation Node requires space used by the CSF
 - Servicing elements utilized for "Transportation" tasks are unavailable for other servicing activities

Selected Evolutionary Study Results

Additional studies include an evaluation of an alternative option for user servicing system growth and assessing the FTS's capabilities along with the hooks and scars necessary to satisfy user servicing requirements.

The alternative space station growth option is one which may be useful for certain specific cases, such as, hazardous material handling, servicing oversize payloads, and servicing contamination sensitive equipment. The FTS studies concluded that the FTS's capabilities will satisfy growth user servicing requirements, as they are currently defined, however, neither the growth servicing requirements nor the FTS evolutionary capabilities are well defined.

Selected Evolutionary Study Results

- Alternate Servicing System Growth Options are available for specific activities
 - Hazardous material handling
 - Payloads too large to service in the CSF
 - Reduced contamination potential (both to and from other SSF payloads/equipment)
- Flight Telerobotic Servicer will satisfy growth servicing requirements, as defined
 - Growth servicing requirements require better definition
 - FTS evolutionary capabilities also require better definition

Conclusions

Regardless of the evolutionary path chosen, SSF will support users in the form of attached payloads, free-flyers, and co-orbiting platforms. These users will continue to require servicing as a part of this support. Therefore, Freedom evolution will not impact the need for a user servicing system.

The integration of existing and growth SSF support elements makes it possible to meet all known user servicing requirements. The design of the Customer Servicing Facility accommodates all the growth servicing elements in one facility. This in turn reduces the interface requirements for the growth servicing elements to a single interface into the SSF.

Conclusions

- The need for user servicing is independent of station evolution
- All known user servicing requirements are satisfied by the planned growth user servicing capabilities
- The Customer Servicing Facility simplifies Freedom hook and scar requirements for user servicing evolution
 - CSF accommodates all other growth elements
 - This results in a single interface to Freedom for all growth elements

"Rephased Baseline" Changes to User Servicing

The very existence of the user servicing system in the Space Station Freedom Program is uncertain – the most likely scenario is that it has been eliminated. The "Rephased Baseline" by Langley and the Configuration Budget Review proposed the elimination of user servicing and the deletion of all scarring and servicing accommodations for all phases of the program.

This results in the elimination of the CSF, thereby eliminating the thermal/contamination controlled environment, eliminating SSF accommodations for the OMV, and eliminating unpressurized storage for supplies and spares.

"Rephased Baseline" Changes to User Servicing

- User servicing existence in SSF Program uncertain
 - GE contract for servicing terminated
 - GE subcontract with TRW for servicing architecture terminated
 - All servicing architecture work deleted from SSF Program
- Configuration Budget Review (CBR) proposed the following:
 - Deletion of all scarring for all phases of the SSF Program
 - Deletion of all servicing accommodations for all phases of SSF
 - Deletion of all provisions for storage and staging accommodations specified in the PDRD
 - CSF eliminated - no thermal/contamination protection from the environment
 - OMV storage eliminated - no Space Station Freedom accommodations for the OMV
 - Supplies and spares storage eliminated

"Rephased Baseline" Changes to User Servicing

The total available EVA time has been drastically reduced with EVA only available while the shuttle is docked at the SSF. This EVA will be utilized primarily for SSF maintenance and relies upon the shuttle suits - not SS suits. The remaining time may be used for user servicing - but only on a contingency basis.

To accommodate this decrease in available EVA time the CBR has proposed robotics, specifically the FTS, as the primary method for payload servicing. However, recent robotics studies indicate that utilization of robotics to perform many high fidelity tasks takes longer than if performed by EVA. In addition, the payloads are required to be robot-friendly.

"Rephased Baseline" Changes to User Servicing

- Total SSF EVA hours available drastically reduced
 - Space Station suits no longer planned for EVA
 - EVA for payloads performed on a contingency basis
- CBR proposed robotics (specifically the FTS) as the primary means of changing payloads
 - Payloads should be designed primarily for FTS handling
 - Recent studies indicate that high fidelity tasks, on average, take longer when performed robotically

"Rephased Baseline" Conclusions

The existence of the user servicing system in the SSF Program may be eliminated, however, the requirements to service user hardware still exist. Relaxed contamination requirements cause a greater need for enclosed environment/contamination protection. The lack of storage space limits the capabilities of the user since it must find a way to accommodate supplies and spares. The lack of storage also precludes docking the OMV on SSF. The impacts of the "rephased baseline" result in a greater dependency on robotics and an elimination of EVA available to satisfy these requirements.

"Rephased Baseline" Conclusions

- The scope of user servicing in SSF Program uncertain, however the requirements for servicing still exist
- Specific user requirements will not be met due to the impacts from the "rephased baseline"
 - Greater need for enclosed environment/contamination protection
 - Storage will not be available
 - Checkout capabilities will be limited
- Changes suggest utilization of robotics (specifically the FTS) to satisfy some of the major servicing requirements

Acronyms

APAE -	Attached Payload Accommodation Equipment
CBR -	Configuration Budget Review
CETA -	Crew and Equipment Translational Aid
CSF -	Customer Servicing Facility
EVA -	Extra-Vehicular Activity of a crew member
FTS -	Flight Telerobotics System
IVA -	Intra-Vehicular Activity of a crew member
MSC -	Mobile Servicing Center
MTFF/ESA -	Man Tended Free Flyer / European Space Agency
NSTS -	National Space Transportation System
OMV -	Orbital Maneuvering Vehicle
ORU -	Orbital Replacement Unit
OSCRS -	Orbital Spacecraft Consumables Resupply System
SPDM -	Special Purpose Dexterous Manipulator
SSF -	Space Station Freedom
STV -	Space Transfer Vehicle
ULC -	Unpressurized Logistics Carrier